Art. XII.—*Erosion and Sedimentation in Port Phillip Bay, Victoria, and their bearing on the Theory of a Recent Relative Uplift of the Sea Floor.*

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Contents.

I.—Introduction and Acknowledgments.

With the aid of a grant from the Trustees of the Council for Scientific and Industrial Research, an investigation of the shores of Port Phillip Bay has been undertaken for the purpose of ascertaining, if possible, where erosion and sedimentation are now taking-place, and in the recent past have taken place, and the bearing of such knowledge on the theory that the land has suffered a recent relative uplift, as deduced from the occurrence of recent marine deposits on the shores (especially the western one) of the bay. It was recognised that the testing of the theory would probably bring many new facts to light, which could not fail to be of value, whatever theory was ultimately adopted. That belief has been fully justified.

The observations hitherto made have been confined mainly to the western side of the bay. The examination is not finished and levels are required. Some detailed mapping is also to be undertaken.

The paper is a summary of the observations made, and of the provisional interpretation of the evidence. It is hoped that details, with illustrations, together with references to any earlier work, will be given in the future.

The writer desires to acknowledge the generous assistance he has received in the prosecution of the work. Maps have been provided or loaned by the trustees of the Council for Scientific and Industrial Research, by the Director (Mr. W. Baragwanath) and the Petrologist (Mr. D. J. Mahony) of the Victorian Geolo-

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He is also much indebted to Professor Douglas W. Johnson, of New York, for his valued advice and discussion of the problems in those parts of the field which the writer had the privilege of showing him over.

II.—Configuration of Port Phillip Bay.

The general outline of Port Phillip Bay is of such a character as to indicate that the bay has had an interesting, although hitherto little deciphered, history. Its formation is generally regarded as being due to a comparatively recent submergence of the land, which was mainly low-lying, and in consequence of which a wide area has been covered by the sea, and now forms the bay.

Following such submergence, the mouth of the bay apparently extended, as suggested by the late Dr. T. S. Hall, from Ocean

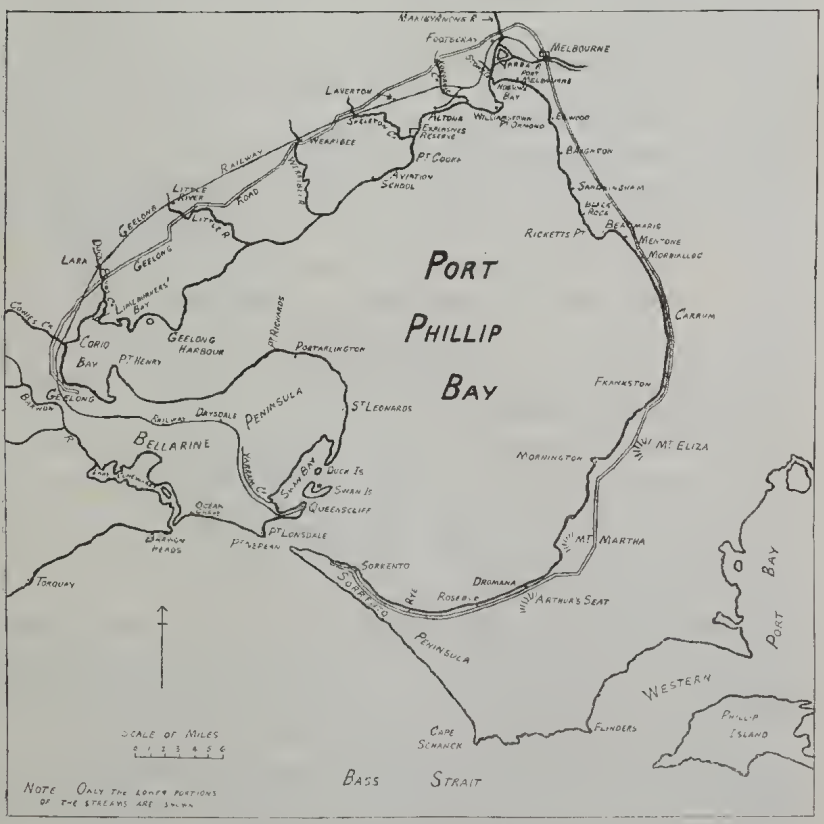

FIG. 1.—Port Philip Bay, Victoria, shewing localities mentioned in text.

Grove to Cape Schanck; but it has been reduced to its present narrow dimensions by the formation of the Sorrento Peninsula and the long corresponding ridge on the opposite side of the bay mouth, extending from Point Lonsdale to Ocean Grove. Such ridges have been formed by the growth of sand dunes, which have become hardened into a sandy limestone (the "dune limestone") by the solution and subsequent precipitation of the calcium carbonate present in the old sand dunes in the form of the hard remains of marine organisms.

Other striking features of the bay are the small Williamstown Peninsula which gives rise to Hobson's Bay; the large Bellarine Peninsula, with Corio Bay on the north; and the pronounced "break back" of the coast line at Beaumaris. By far the greatest drainage that enters the bay does so at Hobson's Bay, its narrowest part (omitting the entrance to Port Phillip).

The origin of these features is not further considered in this paper.

III.—Erosion and Sedimentation along the Coast Line.

Broadly speaking, and with certain exceptions, erosion appears to be taking place on the eastern side of the bay, and sedimentation on the western side. At the narrow head of the bay the delta of the Yarra is probably growing.

Erosion on the eastern side is probably due to the strong winds that prevail on that side, aided by the weak character of the rocks in places. Thus the cliffs from Brighton to Black Rock are mainly practically unconsolidated Tertiary sands, which are easily removed. At Beaumaris the rocks are Tertiary ironstones dipping approximately to the south or south-east. They have offered a stout resistance to the forces of erosion, with the result that the ironstones now form the cliffs of Beaumaris Bay, along the line of which from Ricketts' Point to Mentone the softer rocks have been removed.

At Mentone itself the cliffs are high, but are composed of almost unconsolidated sands, which are being so rapidly removed as to cause anxiety as to the waste of the land.

At Mts. Eliza and Martha and Arthur's Seat, the rocks are granodiorite, considerably decomposed, and erosion here is fairly rapid. High cliffs are formed.

At Mornington there are Tertiary ironstones, similar to those at Beaumaris, and they project as headlands. Tertiary clays and sands, and some small patches of more or less decomposed Older Basalt also occur. Most of the rocks are easily removed.

Along the bay shore of the Sorrento Peninsula are dune limestones, which, on account of the numerous contained patches of loose sand and unindurated material, are being rapidly eroded, resulting in wave-cut platforms and cliffs.

On the eastern side, the streams entering the bay, being few and inconsiderable, carry only a small amount of detritus into the sea. The work of erosion of the coast is thus facilitated.

Summing up the characters of the eastern side of the bay, the coast is largely made up of cliffs of moderate height, composed of various kinds of rocks; and, although some progradation is going on, the coast line is essentially one of erosion. Where a moderate amount of land formation has taken place, it has been mainly in the direction of bay filling, such as the old Elwood and Rosebud Bays.

On the western side of the bay (from the mouth of the Yarra River to the north-western corner of Corio Bay), the rocks are mainly the hard Newer Basalt which resists erosion. The area, however, appears to be one chiefly of sedimentation, portion of the sediments being carried perhaps from the eastern side of the bay by a marine current. Another portion is derived from those brought to the sea by the Yarra and Maribyrnong Rivers. The well developed Werribee and Little Rivers, and minor streams, must, combined, bring to the sea a large quantity of sediment. Erosion is also going on, but in a limited way.

The few observations yet made around Corio Bay and along the northern side of the Bellarine Peninsula indicate that both erosion and sedimentation are taking place, probably, however, with a predominance of erosion.

Swan Bay is a huge area of sedimentation. The rate has doubtless been accentuated by the building of the Queenscliff and the St. Leonard's Spits and of Swan Island, the formation of which has helped to separate the bay largely from the main portion of Port Phillip Bay.

IV.—Description of Individual Localities.

The Yarra Delta.

Much of the original contour of the land cannot now be seen, owing to man's operations. The writer has as yet examined only the part close to the coast, on the left bank of the river, known as the Fishermen's Bend.

An extensive area immediately to the west of the town of Port Melbourne, and a similar smaller area flanking the left bank of the river at its mouth, have been built up by man by dumped material, which is now being cut into for filling elsewhere. Between these areas is a belt of beach ridges and depressions approximately parallel to one another and to the coast, and stretching from the sea coast northwards for a short distance across the Williamstown Road, which lies between the Yarra River on the north and the coast on the south. This belt is practically at sea-level, and certainly appears to have been reclaimed naturally from the sea at present sea-level. The ridges are from one to two feet above the depressions, or old lagoons. Very few recent marine

shells are visible in the deposits, although on the present beach they are not uncommon. No explanation of this peculiarity for the moment is forthcoming.

The deposits now forming on the coast are a continuation of those just described.

The Maribyrnong River at Footscray is tidal, so that the flood plains there are just above sea-level.

The Yarra River as far up as the mouth of Gardiner's Creek is only three feet above sea-level (per J. S. Kitson), and the recent marine shells found when the river was straightened near the Botanical Gardens appear to have been in sections at or below present sea-level.[1]

The known facts, therefore, do not justify the assumption that the Yarra Delta is an upraised sea floor. Rather is it a true delta formed at present sea-level, as would be expected from its location and the quantity of detritus carried to the sea by the Yarra and Maribyrnong Rivers.

Stony Creek, Spotswood.

At low tide, or when the sea is quiet, the Stony Creek, at its mouth on the eastern side of the Geelong railway line, meanders through a flat belt, which is covered with low vegetation. This belt represents an old small bay, formed by subsidence, and since changed into dry land. At a very high tide, however, or when a strong wind is blowing onshore, the sea spreads over the flat, and also upstream beyond the railway bridge. This fact indicates that the area has been silted up at present sea-level, being ordinary bay filling, without any indication of recent uplift, a conclusion negatively supported by the absence of river terraces in the valley.

Williamstown Area.

At the outer beach at the Williamstown township there is a fringe, a few yards wide, of recent marine beds, the top of which is perhaps two or three feet above mean sea-level. Those deposits, however, could easily be laid down by high tides. Relative uplift need not therefore be considered.

Towards the western end of the rifle ranges, which lie to the west of the township, recent excavations, about 50 or 60 yards from the shore, show recent shell beds, which rest on, and between the joints and erosion planes of, the Newer Basalt. The greatest height of the deposits may be from four to six feet above mean sea-level. Other nearby outcrops of basalt a few yards in extent also rise above general sea-level. The basalt is massively jointed, and along the joints erosion by the waves has taken place, but the interspaces are now filled with recent marine shells. These areas are surrounded by silted-up, lower-lying land. The

1.—Gardiner's Creek is about three and one-half miles, and the Botanical Gardens about one mile upstream from the City of Melbourne in a direct line.

same features occur at the water's edge, and the interspaces can now be seen filling with shells, sand and seaweed. Just behind, similar rocks occur, with the interspaces completely filled, and with vegetation growing on the soil-covered surface, which is perhaps three feet above the lower-lying, silted-up land. Examined alone, such basalt outcrops might be interpreted as evidence of recent marine uplift, which would be untrue. Doubts are therefore suggested as to whether the deposits at the excavations mentioned indicate relative uplift.

Small lagoons occur which have been cut off from the sea. These are fringed in places with mangroves, which help (by the collection of mud about their roots) the filling up process which is taking place at present sea-level.

Kororoit Creek.

The valley of this creek in its lower portion has been drowned, and recent marine deposits can be traced along its bed to just beyond the Geelong railway line.

Below the bridge on the Altona railway line the stream meanders through a wide flat, which on its left bank is slightly higher than that on the right bank, which is practically at sea-level, and is covered (so far as can be seen, for the Williamstown Racecourse hides much of the ground) with samphire vegetation. The flat on the left bank is grass-covered and level. The stream is tidal beyond the Altona railway bridge.

If the stream be traced from its mouth to that bridge, on the left bank a practically continuous deposit of recent marine shells occurs, rising to about two feet from the floor of the valley, to which height at high tide the water reaches. This section, therefore, does not indicate relative uplift.

Above the shell beds, from two to three feet of sandy material, free from marine shells, occur. This material, the top of which forms the flat on the left bank of the stream, is evidently non-marine, and apparently has been formed as a flood plain as the mouth of the stream extended seawards.

The land on the right bank is typical samphire country formed at present sea-level.

Upstream from the Altona railway bridge the stream is extremely sluggish, and much of the ground marshy. There is no evidence of rejuvenation to support the idea of a recent uplift.

Live mollusca do not extend so far upstream as their shells are found. This is probably due to the fact that as the mouth of the stream extended seawards the water higher up became too fresh for the mollusca to live in.

Altona Area.

This area, which extends south-westwards from the Williamstown Racecourse to the northern boundary of the Explosives Re-

serve, and north-westwards from the sea to the boundary of the Newer Basalt, comprises a fairly extensive belt of recent marine deposits, with a probable maximum height above sea-level of 10 feet. They are well shown in section on the Altona railway line opposite the Williamstown Racecourse and in the adjacent fields, where, according to Grant and Thiele, their upper surface is $7\frac{1}{2}$ feet above ordinary high water.

The association of these beds and those in the immediate vicinity with tongues of the Newer Basalt, makes the interpretation of the marine deposits difficult. For, as in the Williamstown area, the basalt may rise above the general sea-level, and yet its interspaces and upper surface may contain marine deposits. Moreover, the narrow tongue of basalt which occurs on the right side of the Kororoit Creek valley by the Williamstown Racecourse (see Geological Survey Quarter Sheet No. 1, S.W.), and which is an old peninsula, forms an ideal area for the banking up of marine deposits above mean sea-level, which is the tendency along a shore line. Hence the inference of a rise of 10 feet of the land may not be justifiable.

Two large basins which may be termed lakes, but which are very often quite dry, may be referred to as Lakes Truganina and Seaholme. The former lies to the west, and the latter to the north of Altona township. Immediately to the south of Lake Seaholme, at its western end, is another lake—small, but comparatively long—of the same character, which may be termed Lake Altona, on the northern side of which is a narrow tongue of basalt (not fully shown on the geological map of the area), extending eastwards past the eastern end of Lake Seaholme, and covered by recent marine shells at the eastern end of Lake Altona.

The height above sea-level of the bottoms of these lakes, although not yet determined, is probably negligible. The marine deposits which have cut off these old bays are higher than the present bottoms of the lakes.

Recent marine shells are found on the floors of the three lakes, and are traceable largely around their shores, indicating that the lakes are old arms of the sea, from which they have been cut off by bay bars. The sea water evaporated and marine life ceased to exist, but the remains of brackish water molluscs, which thrive after rain, occur in countless thousands.

Following the building of the bay bars, a series of beach ridges, roughly parallel to one another and to the coast, has been formed, extending to the present coast line. The intervening depressions (old lagoons) have been silted up.

Abundant recent marine shells are found on the ridges and in the depressions, and on the ridges well water-worn pebbles of quartz and other rocks, up to several inches in diameter, occur. Thus the ridges are not old sand dunes, but are true beach ridges, although there is some wind-blown sand on their tops. Some ridges die out or merge into others.

Several ridges occur near the Williamstown Racecourse, where some basalt outcropping in the depressions suggests that perhaps uplift has taken place since the formation of the beach ridges.

The best examples of the beach ridges, however, occur to the south-west of Altona township, between the latter and the Explosives Reserve, where seven or eight distinct ridges parallel to one another can be counted. The formation of the township of Altona has obliterated many of the natural features of the land there.

The general height of the ridges varies from four to probably less than ten feet above sea-level.

Near the Williamstown Racecourse there is a sudden drop from the ridges to a narrow flat which extends to the sea, which fact suggests that the ridges are raised beaches, and that the flat has been formed since the uplift of those beaches. This idea is embodied in the geological map of the district, which separates the flat as a formation distinct from the ridges. The flat has been formed with sea-level as at present, but it is difficult to say definitely the same of the ridges. If it be assumed, however, that both were formed at present sea-level, then the only inference is that for some time past the sea, at the locality mentioned, has lost its power of building strong beach ridges, and that progradation of the land is by ordinary silting only.

Near the Explosives Reserve there is also a fairly sharp rise from the beach ridges close to the sea to those farther inland.

At Seaholme (which is a short distance east of Altona), close to the sea some low beach ridges occur, which have been clearly formed at present sea-level. They pass gradually and apparently without any physical break into the somewhat higher ridges inland. These facts, therefore, tend to confirm the idea of no recent uplift.

Whether there has been a recent uplift or not, it is clear that there has been a reclamation of the land by successive beach ridge building (assuming that such ridges were built so as to project above the then sea-level, about which there seems to be no doubt), and not by a simple uplift of a widely submerged area, although a slight subsequent relative uplift may have occurred. Levels are required to assist in coming to a definite conclusion, but if uplift has taken place, then its vertical extent was probably not more than three feet, after allowing for the height above sea-level, to which the beach ridges were built.

The very small valleys that connect with the larger lakes on the landward side prohibit the idea that the lakes are the remains of the drowned lower ends of such valleys, as the disproportion in the respective areas is too great.

Skeleton Creek Area.

This area includes the country about the mouth of the Skeleton Creek, which in its lower portion meanders through recent marine

deposits which form a low-lying marshy plain, usually covered with a layer of black mud. The waters of the creek are tidal as far upstream as the deposits extend. Near the coast the deposits are at present sea-level, at which they have been formed. As no apparent break occurs in any of the deposits, the whole plain appears to be due to silting at the same level.

Several prominent long ridges rise a few feet above the level of the plain. They are composed of quartzose and shelly sand, with recent marine shells and well water-worn pebbles of quartz, sandstone and basalt. The ridges are, therefore, of marine origin, and at first sight appear to be distinct in origin from the plain, and they have been so mapped by the Geological Survey; but the shells are apparently similar in both cases.

If the ridges represent an uplift, we then have the following history: formation of the ridges as beach ridges at a lower level than at present; uplift of the ridges; then the formation of the marshy plain at present sea-level. The height of the ridges above present sea-level is the only justification for assuming this history; but the height is not inconsistent with the idea of their formation at that level. The more probable history, therefore, appears to be: first, the formation of the scattered beach ridges with sea-level as at present, and then the gradual silting up around them at the same level to form the plain.

A belt of country just south and south-west of the Skeleton Creek, and occupied by the Cheetham Company's extensive salt works, forms a narrow basin trending westerly. Numerous trenches as well as natural outcrops, showing an abundance of recent marine shells, prove that the sea formerly occupied the basin, which may be termed the "Skeleton Basin." The company's works prevent its history from being fully deciphered, but from analogy with other areas on the western side of Port Phillip it may be assumed that the small bay was cut off from the main sea by a bay bar, and that the coast was then prograded by silting and beach ridge building.

No valley connects with the basin. The Skeleton Creek valley is to the north of, and quite separated from it. The basin, therefore, when occupied by the sea was not a drowned valley. It must be tectonic in origin, at least in part. Its origin is discussed in conjunction with similar features in Section VII of this paper.

Point Cooke Area.

On the northern side of Point Cooke there is a narrow belt of beach ridges and old partly silted up lagoons, which form marshy ground at present sea-level. This belt is a continuation of the Skeleton Creek area.

On the south-western side of Point Cooke there is a narrow (perhaps 200 to 300 yards wide on the average) belt of marine deposits stretching (but with an old bay to be presently referred

to) from Point Cooke south-westerly to the Aviation School. At first sight the deposits appear to be parallel sand dunes, the greatest height of which above sea-level is apparently from eight to ten feet. Their crests have probably some wind-blown sand, but the occurrence of recent marine shells and of water-worn rock pebbles indicates that the ridges are beach ridges. The old lagoons have probably been largely filled up with wind-blown sand, although the remains of some are still visible.

The deposits at their inner margin abut the Newer Basalt, and at the junction they are distinctly higher than the basalt, from which they could not have been stripped by erosion (except possibly by wind, which could not, however, remove the included shells and pebbles); and consequently it is difficult to understand how the deposits could have been laid down beneath the sea entirely, if the present edge of the basalt formed the sea coast at a relatively higher level than the present coast, in accordance with the uplift theory. If that were so, there would be a gradual overlap on the basalt without the land surface of the latter being lower than the marine deposits. An alternative is that the ridges have been formed with sea-level as at present.

At the back of the marine beds there is an elongated basin about half a mile long by about one-eighth of a mile wide, which is marked on the Geological Survey Map as the "Sheepwash." It is divided into two sub-basins by a low saddle. The basin is entirely surrounded by basalt, no marine deposits occur in it, and it is obviously due to subsidence of the basalt. Such basins occur on the basalt between Laverton and Geelong.

Another somewhat larger basin lies to the south-west. It contains a salt lake (which may be named Lake Aplin, after the geologist who first mapped much of the ground in the vicinity), the size of which varies according to the season. The basin is surrounded by Newer Basalt except on the seaward side.

Recent marine shells (although none is now living) can be traced practically right around and in the basin. It has, therefore, been an arm of the sea, with a history apparently similar to the Skeleton Basin and the lakes at Altona.

The beach ridges are higher than the present bottom of the lake, and no valley enters the basin.

Little River Area.

There is a fairly extensive belt of recent marine deposits at the mouth of the Little River, but only a cursory examination has been made on the left bank, where abutting the coast is a wide, marshy flat, intersected by small, sluggish, tidal streams, and covered mainly by tall samphire bushes. This area has undoubtedly been formed by ordinary silting at present sea-level.

Behind the belt mentioned is another belt which is less marshy, and may be slightly higher. Numerous drains were being cut

which revealed sections of recent shell beds, but further examination is required.

Lara Area.

The valley of Duck Ponds Creek downstream from the main Geelong Road to the mouth of Limeburners' Bay has been examined. The lower portion of the valley has been drowned, the bay mentioned representing such drowned portion. In Limeburners' Bay, towards its head, there has been considerable silting, which has resulted in the usual type of marshy low-lying land, covered with samphire and formed at present sea-level. On the banks farther upstream are some recent marine deposits, which possibly have been uplifted. If so, they are older than those of the marshy belt. The question of uplift is left open pending further examination.

At the mouth of the bay there is a long, quite recent, spit, stretching from the eastern side probably at least two-thirds across the bay. Low beach ridges, formed with sea-level as at present, also occur.

Geelong and Henry Peninsula Areas.

Geelong.—At the western end of Corio Bay, where the rocks are Tertiary sediments, and where, being at the head of the bay, sedimentation would be expected, practically no progradation of the shore is taking place, but on the contrary the cliffs are receding owing to marine abrasion. Similar features continue past the Geelong township on the southern side of the bay, but to the east of the Botanical Gardens there is an old small bay, the head of which reaches to the Drysdale Road. This area is now completely silted up into a low-lying samphire flat, which is just above, and appears to have been formed at, present sea-level.

Farther east at the south-western corner of the Henry Peninsula, there has evidently been considerable silting, but the extensive salt works there preclude confirmation of this idea.

At the western end of Corio Bay is a band of recent oyster shells, varying in height from nothing to eight feet above present sea-level. This suggests the possibility of uplift, but, on the other hand, it may be the remains of an old beach ridge, or be due to local crumpling.

Henry Peninsula.—This short peninsula, which may be termed the "Henry Peninsula," terminates in Point Henry. At its base it is very low-lying, but the ground gradually rises northwards until it terminates at Point Henry in a somewhat prominent but not high cliff, composed of soft, unstratified, Tertiary clays, which are remarkable in that they have not been entirely removed by erosion.

The Peninsula is being eroded at its northern extremity, but on each side of this point there is a slight accumulation of detritus which has apparently been formed at present sea-level.

At the low-lying base of the peninsula are the remains of an old lagoon, around which a low beach ridge has been built. On all sides of the ridge is a succession of similar ridges and depressions, more or less parallel to the side of the lagoon on which they lie. These ridges extend to the sea on either side.

The peninsula was therefore at one time an island, which, by silting alone, or silting combined with uplift, has been converted into the peninsula.

No heights have been obtained, and in the absence thereof the question of uplift must be left open, but the ground is, as a rule, so little above present sea-level that it is not necessary to assume an uplift. Some deposits, however, are higher than others, so that there is the possibility of two series occurring, the older of which may have been uplifted.

Eastwards for some distance from the Henry Peninsula a narrow strip of land has been reclaimed from the sea. The old sea cliffs are now grass covered and safe (for the present at least) from the attack of the sea by reason of the progradation of the coast line, in part by silting, and in part by the formation of low beach ridges, without uplift.

Portarlington Area.

To the west of the township and of the pier there is a low-lying triangular belt, covered with samphire vegetation, at the base of the old sea-cliffs, and forming a cuspate foreland, which may be termed the "Richards Foreland," as Point Richards is the apex of the triangle. The Geological Survey Map shows the foreland to be two and one half miles in length along its base, and about five-eighths of a mile from the base to the apex. Ordinary silting at present sea-level accounts for the foreland.

To the east of the pier a wave-cut platform, in somewhat decomposed Older Basalt, is exposed at low tide, and the sea is still extending the platform landward by cutting back the cliffs which here form the coast line. Probably the Richards Foreland is being extended seawards, so that only a few hundreds yards apart, progradation and retrogradation are both taking place. The area hitherto examined is very small.

Queenscliff Area.

This area consists mainly of high land formed of dune limestone, which on the ocean side forms steep cliffs due to marine abrasion. The Queensliff Spit, however, which points towards Swan Island and helps to shut off Swan Bay from the main water surface of Port Phillip Bay, has been formed at present sea-level. Narrow marshy belts of marine deposits occur along the south-eastern shore of Swan Bay, together with slightly higher deposits also of marine origin. The latter may indicate relative uplift.

The marine deposits at the south-western end of Swan Bay are included in the description of the Point Lonsdale area.

Swan Island.

Swan Island in its northern portion is divided by a pronounced bay, thus giving rise to two peninsulas pointing northerly and north-easterly respectively. No rocks *in situ* have been found, the island apparently being composed wholly of sand ridges and of silt.

Forming the backbone of the western portion of the island, a prominent sand ridge extends practically from the southern shore to the end of the western peninsula. Short irregular ridges are associated with the main ridge at its southern end, and on its eastern side are several minor ridges roughly parallel to the main ridge. The ridges are covered with vegetation (mainly small trees), and the sand therefore is fixed, except as specified below.

Along the south-eastern shore for perhaps half its length from the southern end, is a ridge of blown sand, this ridge evidently being younger than the main ridge on the western shore.

The eastern peninsula is densely wooded with small trees and shrubs, and the ground is seen to be divided into a series of ridges and depressions, some of which run more or less at right angles to the south-eastern shore, and some more or less parallel to it. The height of the ridges above sea-level is probably not more than four feet.

The remainder of the island is occupied by low-lying marshy ground covered with samphire, the main belt of which lies between the main western and the eastern coastal ridges, and stretches from sea to sea. The whole of this marshy ground is at present sea-level, and it seems to be beyond doubt that it has been formed at that level by ordinary siltation, which has been aided by the pre-existence of the various sand ridges.

In places on the crest of the main western sand ridge, the vegetation has been destroyed, but by what agent the writer does not know. The result has been that much sand has been blown away, to a depth of three to four feet, and this has resulted in a concentration of the recent marine shells (many of which are large) and water-worn pebbles of ironstone, quartz, basalt and sandstone up to three or four inches in their largest diameter, which occur in the sand, and the existence of which is thus strikingly demonstrated. The sand ridge therefore is not of aeolian origin, but is a true beach ridge, the greatest height of which above sea-level is probably about 12 feet, but it has not been accurately determined.

Where the vegetation on the main western ridge has been removed, the sand has been blown by the strong westerly winds against trees and shrubs, partly burying them, and in one instance at least it has passed down on the eastern side of the ridge as a small "sand glacier."

In regard to the question of uplift, it has been shown above that the marshy flats have been formed (and they are still forming) by ordinary siltation at present sea-level. If there has been uplift, it must therefore have taken place before the building of the flats. The sand ridges (with the exception of the eastern coastal ridge) are beach ridges, and it therefore follows that if uplift be evidenced by the occurrence of the beach ridges, then they have been formed as ridges a little above sea-level, and then uplifted to their present height. This requires strong evidence before such an assumption can be accepted; but such evidence is not known to the writer; and the assumption is unnecessary if it be admitted that ridges of the height mentioned can be formed where strong seas prevail, as they do on the eastern side of the island, as will be shown below. The probability therefore is that both the ridges and the flats have been formed with sea-level as at present.

Some of the low ridges of the eastern peninsula run more or less at right angles to the sea coast. These ridges may be the remains of originally more extensive ones, the southern portions of which have been removed by erosion, the removed portions perhaps having had a north-easterly trend. This probability was suggested to the writer by Professor Johnson, and it should be considered in any future study of the island.

On the eastern shore some surveys which have from time to time been made by the Hydrographic Department, show striking changes in the outline of that shore in the course of a few years. Such changes attest the severity of the storms which sweep through Port Phillip Heads, and attack the exposed eastern coast of the island.

The waters on the western shore of the island form Swan Bay, which is remarkably calm and shallow. Hardly any erosion takes place on that shore, and the whole bay is rapidly silting up.

Point Lonsdale Area.

A belt of high land composed of Tertiary sedimentary rocks stretches first, south-westerly from St. Leonard's to Yarram Creek, and then west-south-westerly to Ocean Grove. Another belt of high land, composed of the dune limestone, stretches westerly from Point Lonsdale to Ocean Grove. Point Lonsdale and Queenscliff are connected by a narrow belt composed, at least in part, of dune limestone. The country almost enclosed by the three belts of land referred to consists of flat, marshy ground covered largely with samphire vegetation. Some subordinate low ridges of the dune limestone also occur. The low ground rises somewhat as Ocean Grove is approached.

At the eastern end of this low-lying tract of country is the south-western side of Swan Bay. Recent marine shells are found over the very low ground which occupies most of the area. The

sea has therefore extended much farther west than it does at present—that is to say, the early Swan Bay was very much larger than the present bay, and it had several long narrow islands which now form the subordinate low ridges of dune limestone above referred to.

The long straight lines running south-west and west-south-west, which form the boundaries of the high belt of Tertiary rocks which stretches from St. Leonard's to Ocean Grove, suggest that these lines are fault lines along which the land to the south-east was let down. Evidence, however, confirming the suggestion has not yet been obtained, but it may be remarked that as one approaches from the low ground between the high Tertiary belt and the Ocean Grove-Point Lonsdale ridge, towards Ocean Grove, the recent marine shell beds die out, the country rises somewhat (although much lower than the high Tertiary belt) and the rocks, so far as observed in one or two sections, are ferruginous grits which may correspond with the rocks of the high Tertiary belt. This rising ground therefore suggests that it may represent the down-faulted beds, and also that the sea in its most recent submergence of the land did not extend along the whole base of the Tertiary high land to Ocean Grove. Further investigation, however, is required on these points.

The low-lying area in which recent marine shells occur, between the high Tertiary belt and the Point Lonsdale-Ocean Grove ridge, comprises—(*a*) several low isolated ridges more or less elongated (which were islands in the ancient sea), and a long "peninsula," all of dune limestone; and (*b*) four lakes of varying size.

Three of the lakes are salt, and the largest is a mile and one quarter in length from east to west, by half a mile in its greatest width, although in summer it becomes considerably reduced in area and shows much of its flat sandy or muddy floor, on which common salt is precipitated as the water evaporates. Recent marine shells are found all around the lake, which may be named Lake Lonsdale. Immediately to the west is another small salt lake, a few hundred yards only in diameter, but possessing similar characters to Lake Lonsdale. Both lakes lie along and form part of the low samphire belt.

South-west from the small lake just mentioned is another small circular salt lake, on the margins of which are found recent marine shells. It abuts against the Point Lonsdale-Ocean Grove ridge on the south, and differs from the two previous ones in that it is entirely cut off from the main low-lying area by comparatively high sand ridges. The lake may be named Lake Daintree, after the geologist who geologically surveyed the country in 1861.

The fourth lake is stated on the Quarter Sheet to have fresh water, but at the time of the writer's visit in the autumn it was perfectly dry. Remains of recent marine shells are there found, but it, like Lake Daintree, was also apparently isolated from the

main sea area by wind-blown sand ridges, which are perhaps underlain by the dune limestone. The lake may be named Lake Selwyn, after the first director of the Geological Survey of Victoria.

The chief interest is in Lake Lonsdale. This and the small lake to the west are the only remains now of the extensive sea that formerly occupied the area (omitting Lakes Daintree and Selwyn, which, as shown above, were early cut off). Around Lake Lonsdale some stages of the process of conversion of the sea into land can be traced. Its northern shore abuts almost on to two of the dune limestone ridges mentioned above, at the southern foot of which is a wave-cut platform in the same rock. At its western end, it is cut off from the small lake by ordinary silt and low beach ridges. At its eastern end a bay bar was apparently formed, as the ground rises into a series of beach ridges and depressions which farther east die out to give place to low outcrops of travertine which probably cap dune limestone, although to the east-north-east the marine shell beds extend to Swan Bay.

On the south-eastern side of the lake a series (probably seven or eight of each) of low beach ridges and depressions can be traced southwards and south-eastwards for perhaps 200 yards, beyond which there is a fairly wide long belt of low-lying ground extending to the high coastal ridge. The low-lying belt is apparently a portion of the sea which was early cut off by the building of a bay bar followed by beach ridges, and which later was transformed into a lagoon which now, however, has been changed into practically dry land.

At about the centre of the southern shore of Lake Lonsdale, the high land from the south approaches the shore, then recedes as one goes westward, and again approaches the shore of the lake at its western end. The area so defined between the high land and the present lake was originally an arm of the sea, and probably later an arm of the lake. A beach ridge, acting as a bay bar, has been formed along the northern side of the arm. It brought about the formation of a large lagoon, portions of which still remain.

A low beach ridge now extends practically all around and follows the present outline of the lake, which no doubt it has determined. This ridge is the most recently formed physical feature.

From the imperfect description just given some idea may be obtained of how and by what means the sea has shrunk to its present dimensions, as indicated by Lake Lonsdale.

Whether relative uplift has occurred cannot be stated without some heights of various points in the district being obtained, but the evidence generally is against such theory. Much of the low marshy ground extending westwards from the south-western corner of Swan Bay is undoubtedly mere bay filling at present

sea-level. The ground can be traced without any physical break westwards towards the high Tertiary belt, and into the Lake Lonsdale area by a gap between two of the dune limestone ridges on the northern side of the lake. That being so, the presumption is strong that there has been no recent uplift. When, however, the altitudes of certain critical localities have been ascertained, more light will probably be thrown on the matter.

It has not been proved whether the recent sea (that is, the sea which existed after the formation of the dune limestone) ever extended across where the low sand ridge stands which connects Point Lonsdale with Queenscliff. Its only direct connection with the main waters of Port Phillip Bay may have been through Swan Bay.

On the northern slopes of some of the low sand-covered dune limestone ridges, recent marine shells have been found. The origin of the shells has not yet been satisfactorily determined by the writer.

Rosebud Area.

South-west of Dromana there is a wide extent of low-lying land forming the north-eastern portion of the Sorrento Peninsula, over which area Mr. R. A. Keble guided Professor Johnson and the writer.

The low-lying ground consists of various broad but low beach ridges (which are oriented in different directions) containing recent marine shells, and some water-worn pebbles of quartz and other rocks. Towards the high ground to the south, which consists of dune limestone and forms the backbone of the peninsula, extensive marshy flats surround the ridges, and these flats contain remains of small fresh or brackish water mollusca. It appears, therefore, that the sea has been cut off by a bay bar, and the area gradually changed into a lagoon, in which the organisms mentioned flourished. The greater part of this lagoon has now been silted up. In the way mentioned the land has been prograded to the present shoreline at Rosebud.

The height of the low-lying land is not known. Probably the tops of the beach ridges are not more than 10 feet above present sea-level, but whether there has been uplift since their formation is at present an open question.

Carrum Area.

To the south of Mordialloc the coast line consists largely of low sand dunes, behind which is an extensive low-lying flat area which the Dandenong and other creeks enter. This area was earlier known as the Carrum Swamp. It has not yet been examined by the writer.

Elwood Area.

The small area to the north of Pt. Ormond, formerly occupied by the Elwood Swamp, which has now been drained, was origin-

ally an arm of the sea. This is proved by the fact that recent marine shells occur beneath the two to three feet of black mud which accumulated in the swamp. There can be little doubt that a low sand bar must have cut off this small old bay from the main part of Port Phillip Bay. The marine mollusca died, and the lagoon was gradually changed into a swamp by the accumulation of detritus from the adjacent land.

Allowing for the thickness of the black mud, the marine beds are probably at sea-level, and if that be so, then there is no evidence of uplift. Levels, however, are required.

V.—Wave-Cut Platforms.

A wave-cut platform standing beyond the reach of the waves is excellent evidence of a relative uplift, but neither within the bay nor outside in the immediate vicinity of Port Phillip Heads is there any such evidence.

Fine examples of wave-cut platforms in the dune limestone occur at Barwon Heads, Point Lonsdale, and on the ocean side of the Sorrento Peninsula. A wave-cut platform is also found cut in the Older Basalt just to the west of Cape Schanck. In all these cases the platforms are backed by rock cliffs which are receding owing to marine abrasion, and in this way the platforms are being extended with sea-level as at present. The platforms are exposed at low tide, and are bare of detritus. The slope of the platforms seaward is very gentle; in fact, their surface must be almost horizontal. This raises the question whether the platforms have been cut as they now stand at present sea-level, or whether since their cutting there has been an uplift of the land. If the latter has taken place, then it is a striking coincidence that the platforms should be uplifted just to low water mark. Of course this could occur, but the coincidence emphasises the necessity of caution in dealing with the matter, especially in view of the occurrence inside the bay of marine deposits above sea-level. One would expect, on the theory of uplift, that the platforms would be in similar positions.

If there has been uplift then the coastal edge of the platforms before uplift would be at present sea-level, which means that the slope of the platforms would then be much greater than now, and also that the uplift must have been along a hinge line which would follow the contour of the coast, a phenomenon so remarkable as to call for the strongest evidence of its occurrence. Such evidence is not available so far.

If the uplift extended landward beyond the present coast-line, then the landward edge of the platform must have been lifted above sea-level; and as no remains of the platform above sea-level have been found, it must have been removed by marine erosion. It follows, therefore, that the landward edge of the present platform has been cut at present sea-level.

It is clear that the platforms are now being extended landward by marine abrasion at present sea-level. It may be asked, therefore, why could not the whole width of the platforms have been cut at that level. A difficulty in this connection is to understand how such a high-level platform could be cut for a considerable width. One would think that the waves would practically cease to abrade. That they do not, however, is shown by the fact that, as already stated, the cliffs are still receding, and anyone who has watched the waves at high tide, especially with a strong wind behind them, will realise the great height and power that they attain on the platforms. The facts stated discount the uplift theory.

At one of the stacks on the platform at Point Lonsdale, a few yards from the shore, marine abrasion is now working to a height of five feet above the platform.

On their seaward side the platforms are now being destroyed, so that they are relatively narrow, probably on the average not more than 100 to 200 yards wide. They have been in places breached right through to the sea shore, where the bottom of the sea, although sand-covered, is two to four feet below the surface of the platforms. At their seaward edge the depth of the sea is much greater. There is thus another lower platform being cut by the waves, the surface of which would accord more with the diagrams of the text-books. This suggests that perhaps the present high-level platforms were formed at lower levels, that they have been uplifted, and that the sea, in establishing the old level over again, is destroying the original platforms. It has been shown above, however, that such uplift is improbable, but it is possible that in some way not yet fully understood, the sea can cut two platforms at different levels at the same time under certain conditions, such as the general abrasive power of the sea in a particular locality, which power is influenced by winds and currents, and such as the character of the rocks and the height of the land above the sea.

If the land were comparatively low and the rocks "soft," the formation of the high-level platform might be faster than that of the low-level one, and hence the two platforms, at least for a time, would be found. Increasing height of the cliffs or a change to "hard" rocks, or the occurrence of both these factors, would slow down the formation of the high-level platform, and permit the lower one to gain upon it. Ultimately the higher one might be completely overtaken and disappear.

If the land were high and the rocks "hard," the high-level platform might be destroyed so soon as a few feet in width of it were formed. Hence only one platform—the low-level one—would be regarded as forming, although, in reality, both would be formed, but the high-level one would be almost immediately destroyed.

The destruction of the high-level platform at its seaward edge aids the waves to maintain their abrasive power at its landward edge.

Examples on a small scale of wave-cut rock platforms may be seen within Port Phillip Bay at Portarlington (decomposed Older Basalt), Sorrento and Point Lonsdale (dune limestone), Geelong (Tertiary sediments), Beaumaris (ironstone), and elsewhere. They all occur similarly to the ocean platforms, and the remarks made in regard to the latter apply to the bay platforms.

VI.—River Terraces as bearing on the Question of Recent Relative Uplift.

If there has been a recent relative uplift there should be some evidence of a corresponding rejuvenation of the streams entering the bay. Such a correlation has been claimed in connection with the marine deposits at Altona, and the alluvial terraces of the Moonee Ponds Creek[2] at Moonee Ponds. (See T. S. Hall, "Victorian Hill and Dale.") But before such a correlation can be accepted, it must be beyond doubt that the terraces are really due to uplift, and if that be satisfactorily shown, then it has to be demonstrated that such uplift took place simultaneously with that at the sea coast. Similar evidence should also be forthcoming from other streams entering the bay, but so far that evidence is not known.

In the valleys of the Yarra and its tributaries, the writer is not aware of any terraces that can be definitely stated to be the result of uplift. In the valley of the Maribyrnong River there are several terraces in places, but some of these are clearly not due to uplift, but to aggradation, followed by erosion on changes in the course of the stream. In other places in the same valley, although uplift seems to be the only interpretation of the phenomena, yet the evidence suggests that such uplift took place prior to the uplift (if any) of the recent marine deposits.

The Stony Creek and Kororoit Creek valleys do not indicate any rejuvenation. On the contrary, that of the Kororoit Creek suggests aggradation only, such being due to the submergence of the valley.

In the lower Werribee River valley there are terraces some of which may be due to uplift, but as in the case of the Maribyrnong River, such uplift may have taken place prior to the uplift (if any) of the recent marine deposits.

In the lower Little River valley no terraces have been observed.

The other streams have not yet been sufficiently examined to say whether any terraces occur in them, but such study is in progress.

2.—The Moonee Ponds Creek is just to the east of the Maribyrnong River.

VII.—Origin of the Old Minor Bays.

Eastern Side.

The old Rosebud and Elwood bays appear to be due to the earth movements which formed Port Phillip Bay as a whole by submergence of the land beneath the sea. Prior to that submergence inequalities had been developed on the land surface, and those at Elwood and Rosebud were probably very low-lying areas. Consequently they became submerged at the same time as the remainder of the land which now forms Port Phillip Bay.

Western Side.

These old minor bays, besides being more numerous and yet of smaller area, are more interesting and difficult to explain than those on the eastern side. They cannot be regarded as being entirely due to marine abrasion, since the formation of bays of the character referred to is practically impossible by such means. They occur in the Newer Basalt, and they are probably connected with the subsidences that have taken place on the surface of the basalt during or subsequent to the cooling of that rock. Evidence of such subsidence is provided by the small closed basins, generally from one hundred to several hundred yards in diameter, which occur on the surface of the basalt, and which can only be accounted for by earth movements. Examples of such basins may be seen to the south-west of the Laverton Railway Station; at the "Sheepwash," to the west of Point Cooke; on the left bank of the Little River east of the main Geelong Road; and at other localities. But the old minor bays had of course mouths which connected with the sea, and it is difficult to imagine how such areas could be formed by subsidence alone. A possible explanation is that a number of basins (the bottoms of which were below sea-level) were formed close to the old coast, that erosion took place by marine abrasion which caused the retreat of the basalt until the seaward-facing rim of a basin was breached, and that the sea then entered the basin. If this be the true history, then the basins referred to were not submerged on the general subsidence which formed Port Phillip Bay, and therefore as old arms of the sea they are considerably younger than the Elwood and Rosebud Bays and Port Phillip Bay generally.

It might be urged that such minor basins represent the lower widened portions of old river valleys, but this is not tenable, as no valleys (except some very small ones, which are quite out of proportion to the size of the basins) enter the latter.

VIII.—General Summary of the Facts and their Interpretation.

From the observations so far made it may be said that on the whole, the eastern side of Port Phillip Bay is one of erosion, the primary causes of which are the strong current that apparently

sweeps from the Heads along that side of the bay, and the power of the waves that are formed by the strong southerly and south-westerly winds. These agents of erosion find, in places, nothing but unconsolidated or only slightly consolidated sands, such as those which form the cliffs at Mentone. It is, therefore, not surprising that under those conditions erosion is severe, and causes much anxiety to the foreshore authorities.

There are no streams of any size entering the bay on its eastern side; hence there is scarcely any river-borne detritus to be first removed.

A prominent exception to the general statement made above as to the predominance of erosion on the eastern side of the bay is the Rosebud area, where extensive marine deposits occur. Elwood is a similar area.

The head of the bay is an area of progradation, as shown by the formation of the Yarra Delta. Such a delta is naturally to be expected, considering the very favourable position for its growth, and the large amount of detritus carried into the area from the basins of the Yarra and Maribyrnong River drainage systems.

That portion of the western shore of the bay which extends from the Yarra mouth to the north-western corner of Corio Bay has, in contrast with the western shore, been an area of deposition, as shown by the extensive recent marine deposits which there occur, and which, in some instances at least, have undoubtedly been formed at present sea-level. The deposition may be due to the slowing down of a current from the eastern side of the bay, and to the overloading of the coastal water by the abundant detritus brought to the head of the bay by the rivers mentioned above, part of which no doubt is carried towards the western shore. In addition, two fairly large rivers, the Werribee and Little, and some smaller streams, also enter on the western side of the bay, and thus furnish a further considerable quantity of detritus for land building if it cannot be removed promptly by the sea.

The rocks of the eastern side are also in marked contrast with those of the western, those of the former being, as already noted, in many places quite or comparatively soft; but the Newer Basalt occurs on the western shore, and its erosion by the sea, despite its low height above sea-level, is very slow.

An interesting feature of the western shore of the bay, as above defined, is the number of small bays which formerly existed, but which have been cut off from the main bay by the formation of bay bars across their mouths, following which a series of beach ridges has been formed, thus bringing about the progradation of the land.

Along the western and southern shores of Corio Bay there are cliffs of Tertiary sediments, and there is scarcely any progradation.

Between Geelong and Point Henry an old minor bay has been slowly prograded by silting. There appears to be no bay bar first formed there.

The Henry Peninsula is an example of an island which has been tied to the mainland by silting alone, or silting combined with uplift, and hence may be regarded as an example of a tombolo. At the central part of Point Henry the cliffs of Tertiary clays are receding by erosion, and on either side the land is being prograded by deposition of detritus, the old sea cliffs being now a few yards away from the shore and grass-covered.

Immediately east of the Henry Peninsula, the coast line has been slightly prograded at present sea-level by means of low beach ridges. The old sea cliffs at the rear are now partly grass-covered.

The coast thence to Portarlington has not been examined, but it has some cliffs, and appears to be one mainly of erosion.

At Portarlington there is evidence of both the growth and removal of land.

St. Leonard's has not been examined, but from the geological maps there has apparently been a certain amount of progradation, especially by the formation of a long spit—the St. Leonard's Spit —projecting southwards, and thus helping to isolate Swan Bay from the main bay of Port Phillip.

The area between the high belt of Tertiary rocks stretching from St. Leonard's to Ocean Grove and the Point Lonsdale-Ocean Grove Ridge, is one of great siltation. Much land has been naturally reclaimed from the sea in this area. Swan Bay is the portion as yet unreclaimed, but siltation is rapidly taking place there. On the eastern side of Swan Bay is the large Swan Island, which has been formed by recent beach ridge building and by siltation. The small Rabbit Island, between Swan Island and Queenscliff, and Duck Island, to the north of Swan Island, also apparently belong to the same category, although Duck Island has not been examined. The St. Leonard's Spit hastens the siltation of Swan Bay.

The Queenscliff Spit is the only pronounced area of deposition at Queenscliff, the remainder of the coast being chiefly an area of erosion. Between Queenscliff and Point Lonsdale the coast is one of erosion, although erosion is slowed down by the action of the wind in picking up the beach sand and building up sand dunes.

The present bay side of the Sorrento Peninsula is being eroded by the sea, as shown by the steep cliffs and wave-cut platforms. Deposition seems to be at a minimum, but in the Rosebud area it has been extensive in the past.

The Lake Connewarre area, although outside Port Phillip Bay, may for the sake of completeness be referred to as an area in which much recent natural reclamation of the land from the sea has taken place.

In regard to whether or not there has been a recent small relative uplift of the land, the general weight of the evidence, as outlined in the preceding sections, is in favour of no uplift, that is to say, that all the features of beach ridges, depressions and low-lying flats, which have been taken as evidence of an uplift, and which have been termed raised beaches, may be interpreted as having been formed, with sea-level as at present. The wave-cut platforms inside and outside Port Phillip Bay appear on the whole to support the conclusion stated.

Levels, however, are required in several (or perhaps many) districts, and especially at some critical localities, before a definite pronouncement can be made on the matter, and moreover, certain ground has not been examined, and its examination may give much valuable information.

Apart, however, from the levelling required and the necessity for the examination of further ground, there are certain facts which may be read as indicating uplift. Thus the beach ridges at Altona which are associated with the Newer Basalt, the sudden drop in height in some of the deposits as the sea is approached (as at Altona, the Henry Peninsula, Lara, and, probably, at Queenscliff), and the higher deposits inland than close to the sea, where there are apparently no beach ridges (as in the western portion of the Skeleton Basin and in the Little River area) may be evidence of uplift.

Similarly a prominent oyster band on the western shore of Corio Bay from sea-level to eight feet above it, may possibly be interpreted in the same way, although other interpretations may be suggested.

The possible effect on erosion and deposition within the bay, of the building of the dune limestone at its mouth, has not been considered yet.

Enough has been said to indicate the necessity for further investigations, and to show that for the present the question of relative uplift or not must be left open, although, as indicated above, the weight of the known evidence is against uplift for most of the deposits. Possibly there are two series of deposits in some localities, the older of which may have been uplifted.

Whether there has been a recent uplift or not, the formation of much of the land has apparently been by the building of successive beach ridges (progradation) and not by a simple uplift of a submerged area.